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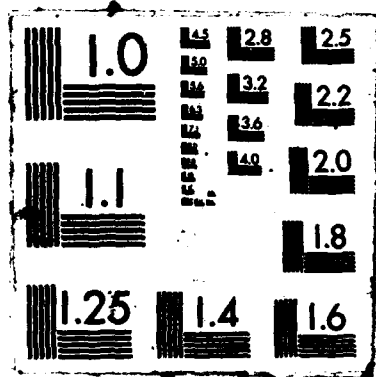
GLOBAL POSITIONING SYSTEM (GPS) ABSOLUTE POSITION OF
TRIDENT II (DSX) THEODOLITE PEDESTAL 1875(U) NAVAL
SURFACE WEAPONS CENTER DAHLGREN VA

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FOREWORD

Results of the positioning of Trident II launch pad 46A from Global Positioning System (GPS) tracking data are presented herein. The work reported was performed by the Space Sciences Branch of the Space and Surface Systems Division under task number K36403.05.

The authors wish to acknowledge Ms. A. Ruth Darnell of the Space Sciences Branch for assistance in collecting and processing data, and Mr. Gary L. Sitzman of the Systems Accuracy Branch, SLBM Research and Analysis Division, for assistance in data collection and for arranging entrance to the launch site. The precise satellite ephemerides were produced at the Naval Surface Weapons Center (NSWC) by Mr. Pat Beveridge and Mr. Everett Swift of the Space and Ocean Geodesy Branch.

The authors also wish to acknowledge the assistance of Mr. Pat Gilligan and other employees of the Defense Mapping Agency at Cape Canaveral, Mr. Doug Burnett and Mr. Bill Hana of the Naval Ordnance Test Unit at Cape Canaveral, and Mr. Roy W. Staton of General Electric Ordnance Systems

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CONTENTS

	Page
INTRODUCTION	1
DATA COLLECTION	1
PRELIMINARY PROCESSING	1
EDITING	2
LEAST-SQUARES SOLUTION	2
KALMAN FILTER SOLUTION	3
WGS-84 TO WGS-72 COORDINATE CONVERSION.	4
RESULTS	4
REFERENCES	6
APPENDIX--PLOTS OF THE RESIDUALS OF FIT.	A-1
DISTRIBUTION	(1)

INTRODUCTION

The Trident II test launch pad 46A is located at the Eastern Space and Missile Center (ESMC) at Cape Canaveral, Florida. The given positions of the pad and the theodolite pedestals around it were determined by using first-order triangulation and traversing techniques from previously established first-order control stations. Since the Global Positioning System (GPS) satellites will be used to help position Trident II missiles during test launches, the Space and Surface Systems Division of the ~~Naval Surface Weapons Center (NSWC)~~ was asked to use GPS tracking data to position one of the theodolite pedestals. This report briefly describes the data collection, analysis, and results in support of this effort. *topic*

DATA COLLECTION

A Texas Instruments 4100 Geodetic Receiver (TIGER) System running the GESAR software was used to collect data for 3 days. The GESAR software is geodetic software written by NSWC with assistance from the Applied Research Laboratory of the University of Texas. A rubidium frequency standard was connected to the TIGER system to improve the long-term stability of the receiver clock.

The TIGER system antenna was located over Theodolite Pedestal 187.5 (THEOD-PED-187.5) of pad 46A. Approximately 7 hr of GPS satellite tracking data per day were collected for days 167, 168, and 169 (June 16 through 18) of 1986. Because of a power loss, tracking on day 169 was terminated early.

Two-frequency pseudorange and continuous count Doppler data were recorded on cassette tapes along with the data time tags, broadcast ephemeris information, and other receiver tracking information. The data cassettes were returned to NSWC where the data were transferred to the CDC 865 mainframe computer system and converted into a standard NSWC file format.

PRELIMINARY PROCESSING

Data that are collected and placed in the NSWC file format are reformatted sequential raw data. The first task for the preliminary processor is to smooth the pseudoranges, compress the data records, and rewrite the data onto a random access file. The smoothing is accomplished by using the phase data as range differences to translate the pseudoranges. During the occupation of this site, observations of pseudoranges and phases were obtained each 30 sec. Compression by a factor of 10 and smoothing were performed simultaneously.

The compression by a factor of 10 produces smoothed pseudorange observations at 300-sec intervals. The smoothing is performed by using a combination of the pseudoranges together with the phases in a manner that keeps the robustness of the pseudoranges but also reduces the noise component.

The ionosphere influences the phase observations in a manner opposite to the effect on the pseudorange. Where the group velocity of the pseudoranges is retarded, the phase velocity of the phases is advanced.² Thus, if a two-frequency ionospheric correction to the L1 phase is computed and applied twice, the

result will be an L1 range observation that contains the same ionospheric effect as does the pseudorange. Differencing these twice-corrected phases and changing them to range units produces range differences from any observation time t_i and an epoch time t_0 . This allows L1 pseudoranges from any epoch t_i to be transferred to the epoch t_0 and averaged. A similar process can be performed with the L2 pseudoranges. The two average values at t_0 can then be used to obtain an ionospherically corrected pseudorange in the usual way.

The utility of using the phase observations to perform the translation of the pseudoranges is that they add little additional noise to the observations. In effect, the new pseudoranges at t_0 have a noise reduced by the square root of the number of observations used to obtain the average. In this case, the factor is 0.32. This reduction applies to the random component, but unless the smoothing interval is very long, the technique does not decrease the quasi-systematic effects such as multipath that appear primarily in the pseudoranges.

The success of the smoothing depends on the presence and continuity of the phase measurements. If there is a phase break somewhere in the smoothing interval, the resulting average will be wrong. However, these errors will be edited later in the processing. The smoothed and compressed observations are written onto a random access file whose record number is defined by the appropriate combination of site, satellite, and time.

EDITING

Editing is performed to eliminate the compressed observations that contain errors introduced by the preliminary processing or errors caused by poor and noisy data. The editing is performed on a site-by-site basis by using a least-squares procedure. The editor does not currently have the ability to correct for clock jumps. Consequently, the data span to be processed must be over a period where the local clock is not reset. Continuity must be maintained in the range biases from all the sites in the solution. In the present case, only one site was processed, but each day had to be taken independently because the receiver was turned off after each observing session. This action reset the local clock offset and eliminated the continuity.

The editing is performed in an iterative fashion by computing the least-squares solution for each site up to six times or until the root mean square (RMS) of the residuals falls below 5 m. The first iteration is performed while holding the site position, tropospheric scaling parameter, and range bias and drift constant at their initial values. Only the satellite bias and drift are allowed to vary. This technique is used to prevent any bad pseudoranges from unduly changing the given site position. After the fit, the RMS of the residuals is computed. Each range residual is tested against a fixed multiple of the RMS; if it is greater, that observation is omitted from the next iteration. The multiple begins at 2.9 and is reduced by a tenth for each succeeding iteration. This editing procedure has the effect of clipping the extreme outliers and keeping the residuals to within 2.9 standard deviations (or less) of the mean solution.

When two consecutive iterations produce an RMS of the residuals below 5 m or when the sixth iteration is reached, the editing ends. After three iterations, a solution with good two-frequency pseudorange data will generally produce an RMS of 2 m or less for each of the sites involved.

LEAST-SQUARES SOLUTION

When the editing is completed, data from all sites are used to perform a single least-squares solution with clock states similar to those that will ultimately be used in the Kalman solution. This preliminary least-squares solution is performed to obtain accurate estimates of the site clock biases. This makes the

observed minus computed values small for the Kalman filter. Experience has shown that the filter performs best when it does not encounter poorly edited data or states with a priori estimates that are far from the truth.

To ensure good performance from the filter, the least-squares clock bias solution is used to recompute the pseudoranges. This removes most of the large site-dependent range bias from the observations. It has the beneficial effect of making the Kalman stochastic clock model operate on pseudorange observations whose clock bias components are of nearly zero mean.

KALMAN FILTER SOLUTION

The Kalman filter program is a UDU sequential processor³ that operates on the pseudorange data in chronological order from each site and satellite. The state vector contains states for the site position, tropospheric scaling parameter, the satellite clocks (when there is more than one site), and the site clock. The latter two are driven by Markov processes. Because there is only one site in the present case, the site clock is the only stochastic state. Since the data have already been edited by the least-squares processing, a single pass through the observations suffices to obtain the solution. A smoothing pass is not performed because the state solution of interest is at the final observation time.

Two forms of residual computations are available after the solution. The first is the usual adjusted residual at a given time using all observations at that time and the current state values. This residual produces the lowest standard deviation and a mean near zero. A second residual is also computed. It is an adjusted residual at a given time using all observations at that time except the final state values. This residual may not be zero mean and usually produces a larger RMS than the first. It is useful for plotting purposes because it shows the variation of the residuals as the solution progresses.

The residuals of the fit are plotted using the final state values (see the appendix). Both methods of computing the residuals are presented in Table 1 along with the number of 300-sec smoothed observations on each day. The operations on day 169 were terminated earlier than on the previous 2 days, which explains the fewer number of observations recorded on that day.

TABLE 1. STATISTICS OF THE RESIDUALS
OF FIT FOR 3 DAYS

Day	Current State		Final State		Number Observed
	Mean	RMS	Mean	RMS	
167	0.11	1.19	-0.17	1.29	286
168	0.04	0.98	-0.92	1.64	293
169	0.06	0.95	-0.55	1.27	195

WGS-84 TO WGS-72 COORDINATE CONVERSION

The solutions were performed by using the NSWC precise ephemerides that were computed in the WGS-84 coordinate system. Therefore, the Earth-fixed position solutions were also in the WGS-84 system. The solutions had to be converted to the WGS-72 system to compare the solutions with the given position. Since there is a shift in the origin along the Z-axis between the WGS-84 and the WGS-72 coordinate systems, and a rotational shift between the two systems in the definition of the X-axis, the Cartesian coordinates must be rotated and translated to convert from the WGS-84 system to the WGS-72 system. The following equations were used to perform the rotation and translation needed to convert the solutions from the WGS-84 to the WGS-72 system.

$$X_{72} = X_{84} \cos(A) + Y_{84} \sin(A)$$

$$Y_{72} = Y_{84} \cos(A) - X_{84} \sin(A)$$

$$Z_{72} = Z_{84} - B$$

A is the rotation angle from the WGS-84 coordinate system to the WGS-72 coordinate system.

B is the distance along the Z-axis from the origin of the WGS-84 coordinate system to the origin of the WGS-72 coordinate system.

X, Y, Z is the position in the WGS-84 or WGS-72 coordinate system.

$$A = +0.24 \text{ sec of arc}$$

$$B = +4.5 \text{ m}$$

Although the value of A that has been agreed upon for WGS-84 is 0.554 sec of arc, the NSWC precise ephemerides were produced in a preliminary WGS-84 system that used a value for A equal to 0.24 sec of arc.

RESULTS

The given position in the WGS-72 coordinate system of THEOD-PED-187.5 of the Trident II launch pad was determined through first-order triangulation and traversing by the Geodetic Survey Squadron of DMA.¹ The differences between the given position for THEOD-PED-187.5 and the positions derived from GPS satellite tracking data are listed in Table 2. The positions in the WGS-72 Cartesian coordinate system and the WGS-72 geodetic coordinate system that were derived from each day's tracking data are also listed in Table 2.

There was very good agreement between the two techniques. The total difference between the given and the derived position for each of the 3 days was less than 2 m, and no component on any day differed by more than 1.5 m. Since the accuracy for the given position was ± 1.0 m standard error in each component,¹ these results are in the acceptable range.

TABLE 2. THEOD-PED-187.5 PRECISE EPHEMERIS ABSOLUTE POSITION SOLUTIONS (WGS-72)

Day 167: SVs 3, 6, 8, 9, 11, 12, 13 Residual S.D. = 1.19 m			
X:	923424.769 \pm 0.075 m	Long:	279.471231642 deg
Y:	-5535240.675 \pm 0.172 m	Lat:	28.457077223 deg
Z:	3021123.230 \pm 0.119 m	Ht:	-23.956 m

Day 168: SVs 3, 6, 8, 9, 11, 12, 13 Residual S.D. = 0.98 m			
X:	923424.596 \pm 0.072 m	Long:	279.471231717 deg
Y:	-5535239.599 \pm 0.166 m	Lat:	28.457089174 deg
Z:	3021124.146 \pm 0.113 m	Ht:	-24.477 m

Day 169: SVs 3, 6, 8, 9, 11, 13 Residual S.D. = 0.95 m			
X:	923424.023 \pm 0.117 m	Long:	279.471224471 deg
Y:	-5535240.476 \pm 0.199 m	Lat:	28.457091171 deg
Z:	3021124.816 \pm 0.176 m	Ht:	-23.480 m

Differences from the Given Position (m)			
Position	Day 167	Day 168	Day 169
Long	0.787	-0.794	-0.084
Lat	-0.368	-0.962	-1.184
Ht	-1.014	-0.493	-1.491
RSS	1.335	1.341	1.905

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2. P. S. Jorgensen, *Ionospheric Measurements from NAVSTAR Satellites*, The Aerospace Corporation.
- 3.. G. J. Bierman, "Factorization Methods for Discrete Sequential Estimation," Volume 128, *Mathematics in Science and Engineering*, Academic Press, 1977.

APPENDIX
PLOTS OF THE RESIDUALS OF FIT

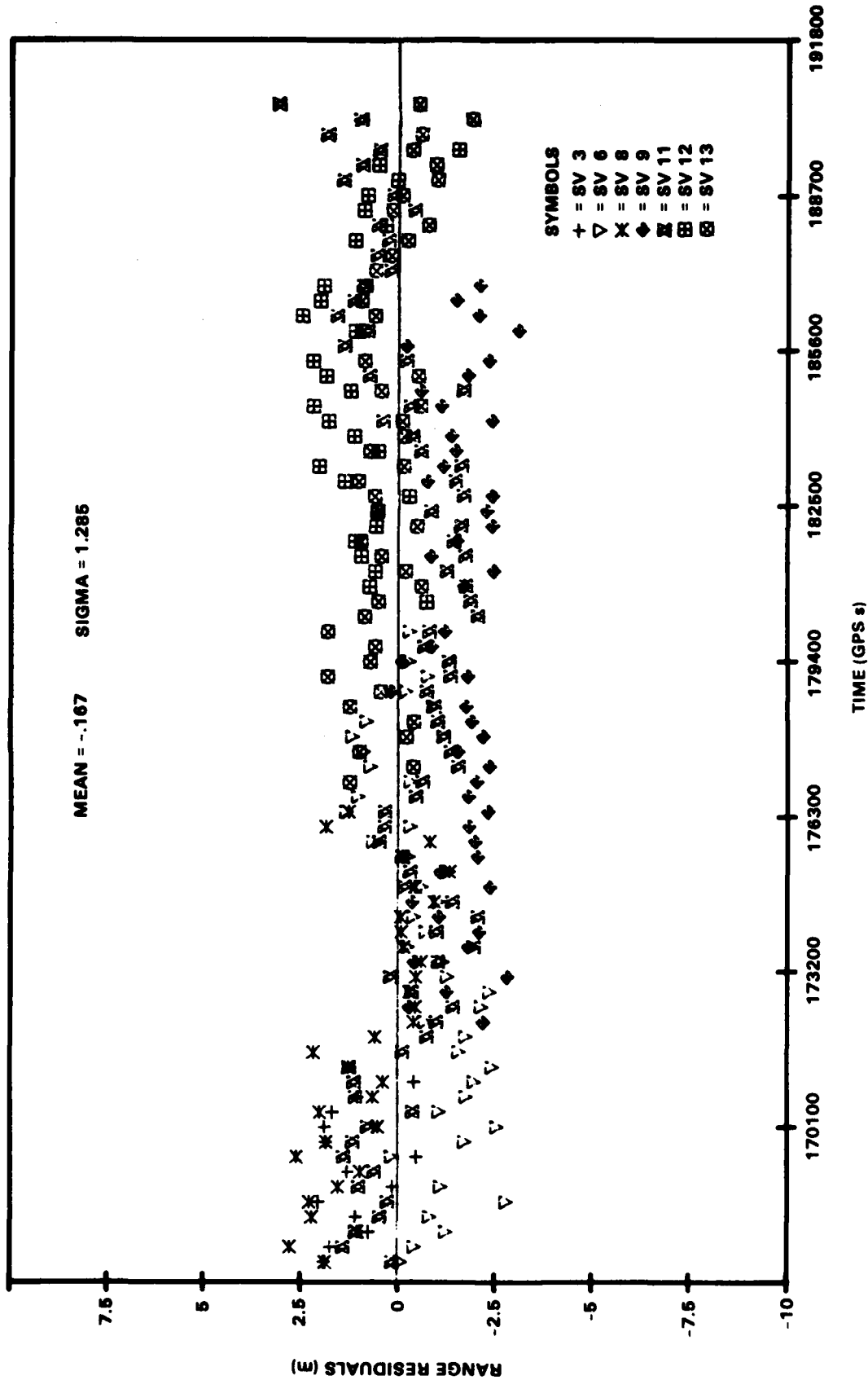


FIGURE A-1. RESIDUAL PLOT AFTER FIT FOR DAY 167

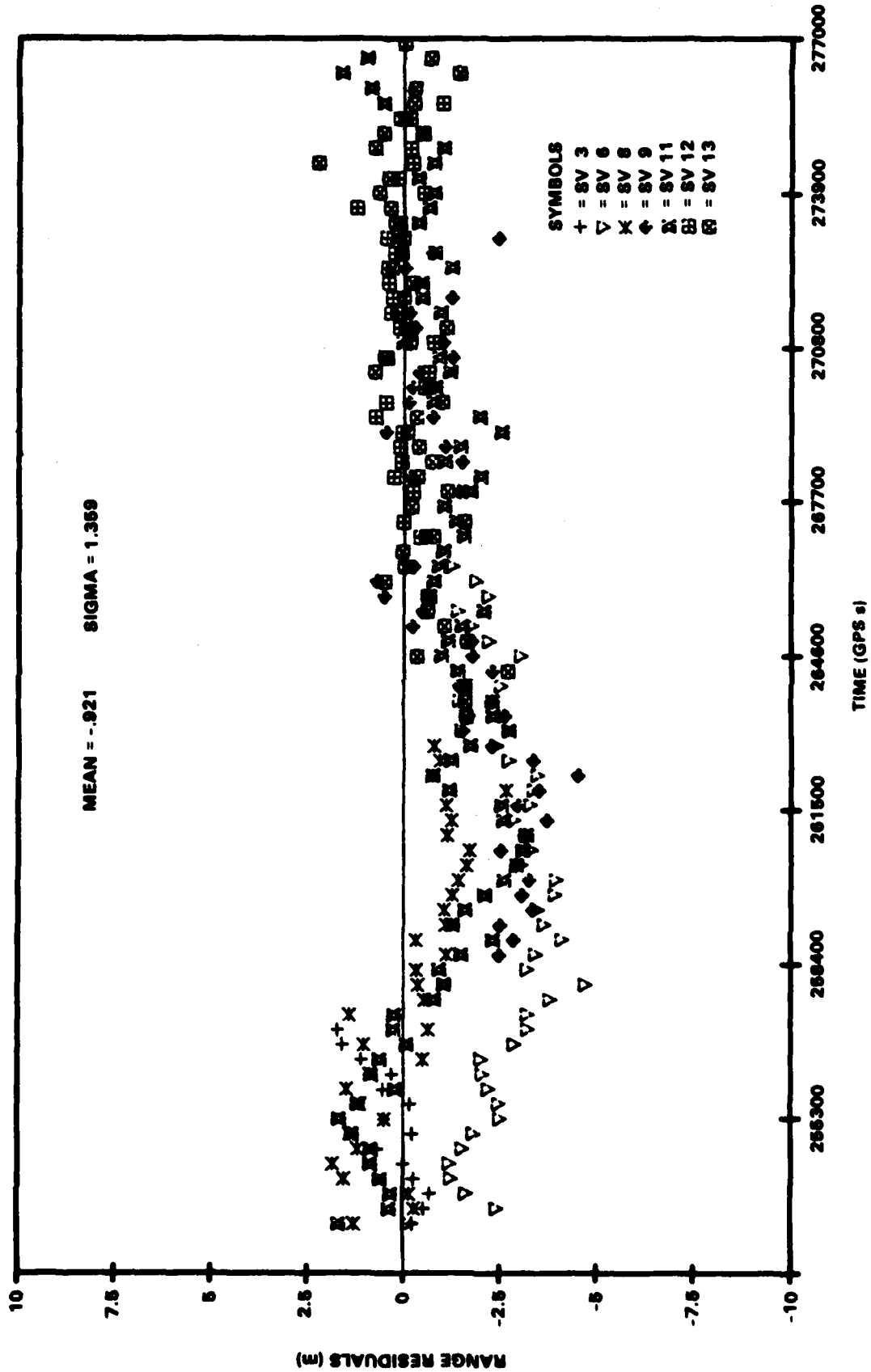


FIGURE A-2. RESIDUAL PLOT AFTER FIT FOR DAY 168

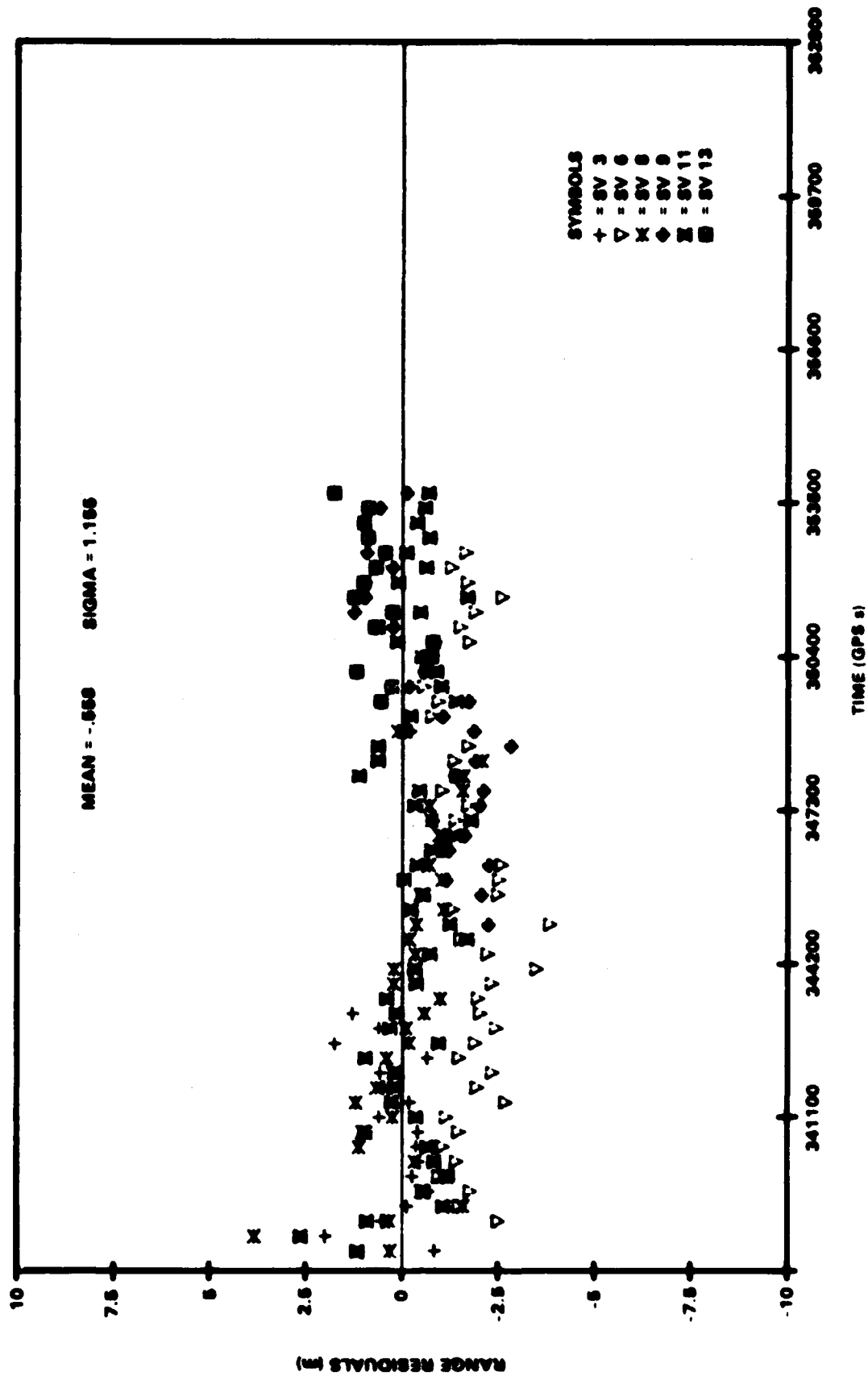


FIGURE A-3. RESIDUAL PLOT AFTER FIT FOR DAY 169

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